Utah State University

DigitalCommons@USU

All Graduate Theses and Dissertations

Graduate Studies

5-1985

An Autecological Study of Dyers Woad (*Isatis tinctoria* L.) on Utah Rangeland

Ann T. Fuller

Utah State University

Follow this and additional works at: https://digitalcommons.usu.edu/etd

Part of the Plant Sciences Commons

Recommended Citation

Fuller, Ann T., "An Autecological Study of Dyers Woad (*Isatis tinctoria* L.) on Utah Rangeland" (1985). *All Graduate Theses and Dissertations*. 6395.

https://digitalcommons.usu.edu/etd/6395

This Thesis is brought to you for free and open access by the Graduate Studies at DigitalCommons@USU. It has been accepted for inclusion in All Graduate Theses and Dissertations by an authorized administrator of DigitalCommons@USU. For more information, please contact digitalcommons@usu.edu.

AN AUTECOLOGICAL STUDY OF DYERS WOAD (*ISATIS TINCTORIA* L.)
ON UTAH RANGELANDS

by

Ann T. Fuller

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Range Science

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1985

ACKNOWLEDGMENTS

I would like to express my deepest gratitude and respect for Dr. Neil E. West. He provided endless hours of assistance and advice.

I would like to thank the Utah Agricultural Experiment Station for providing financial support through Agricultural Experiment Station Project No. 776.

Finally, without the understanding and help of John Tanaka, this thesis would never have been finished.

Ann T. Fuller

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

An Autecological Study of Dyers Woad (*Isatis tinctoria* L.)

on Utah Rangeland

by

Ann T. Fuller, Master of Science

Utah State University, 1985

Major Professor: Dr. Neil E. West
Department: Range Science

Northern Utah rangelands have become infested with dyers woad (*Isatis tinctoria* L.) and control is needed. Mechanical and chemical control on rangelands produce undesirable effects. A possible alternative is biological control, but information is not available on plant response to this control method. This autecological study and simulation of control methods examined dyers woad phenology, seed endurance and response to simulated grazing, hand rogueing and plowing. The phenology study documented dyers woad growth patterns from May 1982 to November 1983. During the first year, 65 percent of the seedlings died while the remaining 35 percent grew rosette leaves. During the following growing season, 50 percent of the remaining population flowered and died. The other 50 percent continued to grow rosette leaves. The seed endurance study showed seed viability remaining high and relatively stable, but germination decreased during the ten month study period. Methods used indicate future germination and viability studies should more closely simulate field conditions. The simulation of control methods involved clipping dyers woad once at three different heights to simulate grazing, hand rogueing and plowing on three different dates that correspond with the phenological stages of initial rosette growth, pre-bolting, and post-bolting. Simulated grazing stimulated plant survival and growth. Simulated plowing and hand rogueing reduced plant survival. Treatment at all three levels after initial rosette growth depressed flowering for one year. Treatment to simulate plowing and hand rogueing during initial rosette growth depressed flowering compared to the untreated controls. Treatment early in the growing season did not significantly affect plants receiving simulated grazing. Seed production was depressed by simulated plowing but was promoted by simulated hand rogueing when compared to untreated controls. The ability of plants to survive and/or flower after treatment could not be predicted from this study because a one time clipping of dyers woad did not produce significant population decreases. A more severe treatment in the form of more clippings per season is suggested for future study.

(54 pages)

CHAPTER I

INTRODUCTION

Dyers woad (Isatis tinctoria L.) has become a formidable opponent for more desirable range plants and cultivated crops on Utah range and croplands. Evans and Chase (1981) estimated that dyers woad reduced crop and rangeland production in three northern Utah counties by two million dollars in 1981. In addition, the size of dyers woad infestation has doubled in the last decade causing widespread concern among farmers and ranchers (Evans and Chase 1981). The concerns of farmers and ranchers have been reduced on croplands through mechanical or chemical control of dyers woad. However, these methods are not now suitable for rangelands due to undesirable effects of herbicides and machinery on associated desirable forage, generally rough topography and questionable present net worth. This study addressed the feasibility of another control method, biological control through grazing.

Observations of grazed and ungrazed pastures by Karl Parker (1982), retired Range Extension Specialist, indicated that the grazed pastures had fewer dyers woad plants than the adjoining ungrazed rangelands. Grazing, also, apparently controlled seed formation and future growth (Parker 1980). Thus, biological control through grazing was a definite possibility, but not a certainty. An expensive grazing project was not considered to be feasible on the mere possibility of control. More information on the autecology of dyers woad and its response to known times and levels of damage was needed and gathered by this study. The manipulative study attempted to determine the severity of damage needed to cause mortality and inhibition of seed formation by varying clipping intensity and timing. The most important and tractable autecological information seemed to be phenology, seed germination and seed endurance.

The following objectives were addressed:

Objective 1: To describe the phenological stages of *Isatis tinctoria* L. in northern Utah.

Objective 2: To determine whether germination and viability of *Isatis tinctoria* L. seeds change over time.

Objective 3: To determine the effects of intensity of single clippings on mortality of *Isatis tinctoris* L.

Objective 1 involves a descriptive study whereas the other objectives lead to the following testable hypotheses:

Hypothesis 1: *Isatis tinctoria* L. seeds will show reduced viability and germination rates with aging.

Hypothesis 2: Significantly greater mortality rates will occur for individuals clipped above ground than for plants clipped at or below ground.

Hypothesis 3: Significantly greater mortality rates will occur for individuals clipped prior to bolting than for plants clipped after bolting.

Hypothesis 4: Significantly greater mortality rates will occur for treated versus control plants.

CHAPTER II

REVIEW OF LITERATURE

Dyers woad (*Isatis tinctoria* L.), a member of the Brassicaceae (mustard family), has been classified in a number of common references as a winter annual or biennial (Rydberg 1917, Gilkey 1957, Baker 1965, Varga and Evans 1978). It germinates in the spring or fall and grows first into a rosette. During a subsequent growing season, the rosette "bolts" or grows a stalk which flowers and produces seeds.

The rosette and stalk forms can be grouped according to distinct morphological features. The rosette form has oblanceolate, petiolate basal leaves. The bolted form has a stalk, inflorescence and seeds. The stalk can grow from 3 to 10 decimeters in height with lanceolate, sessile leaves (Gilkey 1957). The inflorescence is a brilliant yellow umbel which produces black or purplish brown fruits. The fruits are pear-shaped, woody silicles which encircle yellowish brown seeds (Hurry 1930). Both forms grow from a thick tap root which may exceed 1.5 meters in depth (Varga and Evans 1978).

Reproduction from either form is possible for dyers woad. The rosette can reproduce asexually from the tap root. The bolted form can reproduce asexually from the root or sexually from the seeds (Gilkey 1957).

Reproduction by dyers woad seeds is both typical and atypical of the Brassicaceae. Typically, the seeds germinate quickly followed by the rapid appearance of numerous seedlings (King 1966). Atypically, the seeds do not dehisce from the fruits and the fruits are coated with a germination inhibitor. This germination inhibitor effectively suppresses germination of competing grass and forb species including other Brassicaceae and threshed dyers woad seeds (Young and Evans 1971). In addition, dyers woad seeds have no dormancy period (Evans and Gunnell 1982).

Dyers woad seeds have been sown and the plants used by man for centuries. Dyers woad was a native of the southeastern USSR and was spread by humans throughout the eastern hemisphere during prehistoric times (Varga and Evans 1978). The Greeks and Romans used dyers woad as a medicinal herb (Baker 1965). Warriors of ancient England stained their bodies blue with dyers woad according to reports by Julius Caesar, Pliny, Ovid, and Heriodian (Hurry 1930). Actual cultivation of dyers woad can be traced back to early Christian times through Egyptian farm leases and revenue accounts (Hurry 1930). During the Middle Ages, large scale cultivation which required international control began in England and France and spread to Germany and Italy (Hurry 1930, Baker 1965).

Dyers woad was cultivated primarily for a blue dye and secondarily for paints and medicines. The blue dye was derived from insoluble indigotine. The indigotine was extracted from the rosette leaves during a lengthy process. The whole process took several months to complete and was performed totally at the woad mill (Hurry 1930).

The process started with the pulping of fully grown succulent rosette leaves in a roller house. The leaves were ground to a pulpy mass and shaped into small balls for drying. These balls were placed in drying ovens from one to four weeks. After drying, the balls were taken back to the roller house and ground to a powder. The powder was taken to the couching house, sprinkled with water and fermented for nine weeks. The fermented paste was dried and refermented to produce the white powder in which insoluble indigotine was concentrated (Hurry 1930).

Artist paints were by-products of dyeing cloth with dyers woad. The paint was obtained from the foam produced in the woad vats. Woad vats held the aqueous solution of indigotine for dying clothes (Hurry 1930).

Finally, dyers woad was used as a medicine. The leaves were found to have antiseptic, astringent and wound-healing properties (Hurry 1930).

Dyers woad was an important European product until the industry fell apart in the seventeenth century. The industry died for a variety of reasons which included the introduction of Far East indigo. Indigo which produced brighter colors for a lower price was introduced at a time when production of European dyers woad had decreased due to poor farm management (Hurry 1930).

Dyers woad made its first appearance in the United States during colonial times. It was initially cultivated in Virginia for exportation (Hurry 1930, Young and Evans 1971). Later, dyers woad spread to northeastern California, southwestern Oregon, Idaho, Montana, Wyoming and Utah (Varga and Evans 1978).

Dyers woad was observed and reported in Utah by Rydberg (1917) as far back as 1917 in his Flora of the Rocky Mountains. The earliest dyers woad collection in the Intermountain Herbarium was by Bassett Maguire from Perry, Utah in 1932 (Evans and Gunnell 1982).

Since 1932, dyers woad has been rapidly expanding its distribution and increasing in abundance in northern Utah counties. By 1981, the infestation in Box Elder, Cache and Rich Counties reduced crop and forage production by an estimated two million dollars annually (Evans and Chase 1981). These major losses, plus the increased visibility of dyers woad every spring, stimulated public interest in control.

Several herbicidal and mechanical control methods have been developed and are available for public use. Mechanical methods in the form of early spring tillage or soil preparation can control dyers woad in alfalfa or small grains. Herbicides recommended for use on croplands are 2,4-D in the spring and atrazine, metribuzine or simazine in the fall (Higgins and Tovey 1972, Evans and Chase 1981).

Additional information on dyers woad is available in Anderson and Holmgren (1966), Welsh and Moore (1973), Evans (1976), Holmgren and Anderson (1976), Kotter (1976), Welsh and Reveal (1977), Holm et al. (1979) and Lacey and Fay (1984).

CHAPTER III

MATERIALS AND METHODS

Study Site

This study was conducted on foothill rangeland along the western base of the Wellsville Mountains in eastern Box Elder County, Utah (E 1/2 SE 1/4 Sec 29 T12N R2W; E 1/2 NE 1/4 Sec 32 T12N R2W). This foothill rangeland had a Sterling gravelly loam soil on 6 to 20 percent slopes (Soil Survey Staff 1975). The vegetation was dominated by bluebunch wheatgrass (*Agropyron spicatum*), sandberg bluegrass (*Poa sandbergii*), big sagebrush (*Artemisia tridentata*) and cheatgrass (*Bromus tectorum*). The range site was classified as an upland loam (Soil Survey Staff 1975). The study site was on a west-facing slope between 1480 and 1525 meters elevation with an estimated average annual air temperature of 9°C. The average annual precipitation was probably 44 cm (Soil Survey Staff 1975).

The northern half of the study area was privately owned by J. D. Norr and the southern half by Bryan Marble. In late May 1982, the southern half was aerially sprayed with 2,4-D, but the owner was skeptical of the effectiveness of the spray (Marble 1984). The northern half was not sprayed and neither half has been purposely grazed in over 20 years (Norr 1983).

Phenology Study

Planning a successful control program, such as grazing, requires prior knowledge of plant growth responses, but no information was available for dyers woad. Certain phenological stages may respond to control more successfully than others. Categorization of the stages and their time of occurrence would fill one more blank space in a grazing study design.

Ninety dyers woad plants on each site were randomly chosen for the phenological study. These plants were also used as controls for the 1982 clipping study. The plants were assigned one of nine phenological stages (Table 1; West and Wein 1971, Everett et al. 1980). Assignments were made monthly during slow growth and biweekly during rapid growth. Phenology assignments were recorded from May 1982 to November 1983. In addition to the phenological assignments, rosette diameter, rosette leaf number, basal diameter, seed number,

Table 1. Phenological stages and corresponding numbers assigned to dyers woad.

Number	Stages
0	Dormancy
1	Leaf growth
2	Stem growth
3	Floral buds developing
4	Flowering
5	Seed development
6	Seed ripening
7	Seed dissemination
8	Death

stalk height and stalk leaf number were measured and recorded. Photographs were taken of each plant on almost every observation date.

A field weather station was placed in the center of the study site. Temperature and precipitation data were gathered to aid interpretations of phenological results. A micrologger, Campbell Scientific Company model CR 21, was set up in September 1982 and programmed to record daily air temperature, relative humidity, and soil temperatures at 2 and 10 centimeters below the ground surface. Due to technical difficulties, data collection did not begin until February 1983. A continuously recording rain guage was used to gather monthly precipitation data beginning June 1982. To compensate for the lack of long term data, average precipitation and air temperature data were extrapolated from Bear River Bird Refuge and Corrine weather data.

Germination Study

The time required for a successful control program is directly linked to the life span of seed of the target species. A long-lived seed will require a longer time period for successful control than one with a shorter average seed longevity. In order to properly plan control strategies for dyers woad, seed viability and germination studies were needed.

Viability and germination studies were conducted simultaneously with hand-harvested fruits. The studies were conducted on seeds removed from fruits stored in the laboratory and in the field. The fruits were harvested 8 July 1982 from both sites. The "lab" fruits were stored inside at room temperature for the duration of the study and the "field" fruits were stored inside for one month prior to placement in the field. On 8 August 1982, 12 fiberglass mesh bags were filled with 120 fruits and buried under approximately 1 cm of soil on each site. One bag was removed each month from each site and returned to the laboratory for germination and viability tests.

In the laboratory, "field" fruits were opened and the seeds were sorted into three categories: germinated, bad and testable. Germinated seeds had germinated in the field. Bad seeds were moldy and black. Testable seeds were ungerminated yellow-green seeds and used in the germination and viability tests. The seeds were threshed from the fruit to prevent autotoxic delays of germination (Young and Evans 1971).

The germination tests were conducted at a constant temperature of 25°C. The seeds were placed in petri dishes containing 5 grams of sterile sand and watered approximately every 48 hours with 1 ml of water. The seeds received 12 hours of continuous light followed by 12 hours of darkness each day. A cool white fluorescent light was used as the light source (Association of Official Seed Analysts 1970, Bonner 1974). The seeds were germinated under these conditions for 14 days with a germination count on day 14. Seeds were considered to be germinated when the radicle was 2 mm long (Young and Evans 1978).

Ungerminated seeds were subjected to viability tests on days 15 and 16. The seeds were soaked in 2,3,5-triphenyltetrazolium chloride for 48 hours. Colorless 2,3,5-triphenyltetrazolium chloride stains the living embryo tissue of viable seeds red (Moore 1973). At the end of 48 hours, viable seeds were counted and added to the germinated seed counts for the viability totals.

Chi-square tests of significance at the 95 percent confidence level were used to determine if significant differences existed between field sites, storage location and months (Cochran and Cox 1957, Steel and Torrie 1980).

Clipping Study

The possibility of control of dyers woad on rangelands through livestock grazing was the driving force behind this study. A grazing simulation was deemed to be more tractable and less expensive than actual grazing trials, at least for initial efforts to define feasibility of this possible control. The grazing simulation chosen was clipping.

The effects of clipping were to be determined by defoliating a population of dyers woad plants at three different heights and at three different times on two replicate sites. A different set of controls were chosen for each treatment time and site. The three treatment heights were: 5 cm below ground, ground level and 1.5 cm above ground level. The three treatment times were 1 May 1982, 25 June 1982 and 1 April 1983. The heights were chosen to simulate below ground plowing or mechanical control, ground level hand rogueing or cultural control and above ground sheep grazing or biological control. The times were chosen to correspond to certain phenological stages: pre-bolting in late spring, post-bolting in mid-summer and initial rosette growth in early spring.

Plants were randomly chosen from two replicate sites. The sites were marked off with twine and stakes to provide trails to the plants. Site one had 20 rows 35 meters long. Site two had 40 rows 25 meters long. Each row was 1 meter wide and each trail was 1/2 meter wide to prevent trampling effects. Plants were randomly located first by row, second by meter, and third within a meter square frame. Each meter square frame was subdivided into 16 subunits and the interior four subunits were used to randomly locate the plants. Within the randomly selected subunit, the dyers woad rosette meeting minimum size requirements and closest to the frame center was marked with a painted wooden dowel. The dowel was placed 15 cm to the north of the chosen rosette. The minimum rosette size requirements were three rosette leaves and a rosette diameter of 2 centimeters. This was the smallest size of dyers woad plants that could be definitely identified.

One hundred eighty plants were chosen from each site for the 1982 clipping times. The 180 plants were randomly assigned to the clipping height treatment or control until 45 plants had been assigned to each clipping height and control category. The procedure was repeated in 1983 with 120 plants per site and 30 plants per treatment and control.

Prior to clipping in June 1982 and April 1983, rosette diameter, rosette leaf number and basal diameter were measured for each treated and control plant. Rosette diameter of each treated and control plant was measured directly before the May 1982 clipping.

After clipping, presence, rosette diameter, rosette leaf number and basal diameters were recorded for each plant at six week intervals. In addition, stalk height, stalk leaf number and seed numbers were recorded for bolted plants.

The presence or absence and live or dead data were analyzed by Chi-square tests of significance (Cochran and Cox 1957, Steel and Torrie 1980). The tests were performed to determine if significant differences existed at the 95 percent confidence level between sites, clipping heights and clipping times. The 1983 clipping data were analyzed separately from those gathered in 1982 due to differing climatic patterns.

An analysis of variance was used to determine if significant differences at the 95 percent confidence level existed between pre-clipping rosette diameter, rosette leaf number and basal diameters (Ryan et al. 1976, Steel and Torrie 1980). This test was performed to determine if a relationship existed between plant size and the ability of a plant to survive clipping (Werner 1975, Gross 1981). Initially, rosette diameter, rosette leaf number and basal diameters were tested for normality and homogeneity of variance (Ryan et al. 1976, Steel and Torrie 1980).

The percentage of plants which flowered in 1983 was determined and analyzed with Chi-square tests of significance at the 95 percent confidence level (Cochran and Cox 1957, Steel and Torrie 1980). The tests were performed to determine if a significant relationship existed between rosette diameters, rosette leaf numbers and basal diameters and the ability of dyers woad to flower.

CHAPTER IV

RESULTS

Phenology Study

The phenological progression of dyers woad control plants over two growing seasons exhibited several seasonal responses (Figure 1). The spring and fall were dominated by leaf growth. Dormancy occurred in either summer or winter corresponding to cold temperatures or hot, dry climates (Figures 2 and 3). Flowering occurred late in the spring. The total process from stem growth or bolting to seed development took approximately eight weeks. Mean stem growth was 10 cm per week from mid-April until the end of May. Each stem supported an average of 20 leaves. Approximately 383 seeds were formed per plant.

Sixty-five percent of the plants died during the first growing season and only 1 percent of the plants that were originally marked flowered (Figure 1). By the second growing season, 35 percent of the plants were still alive and approximately half flowered and produced seed. After flowering, all these plants died, but approximately 12 percent were still alive and could flower during the third growing season.

Germination Study

Germination of dyers woad seeds stored in the field ranged from

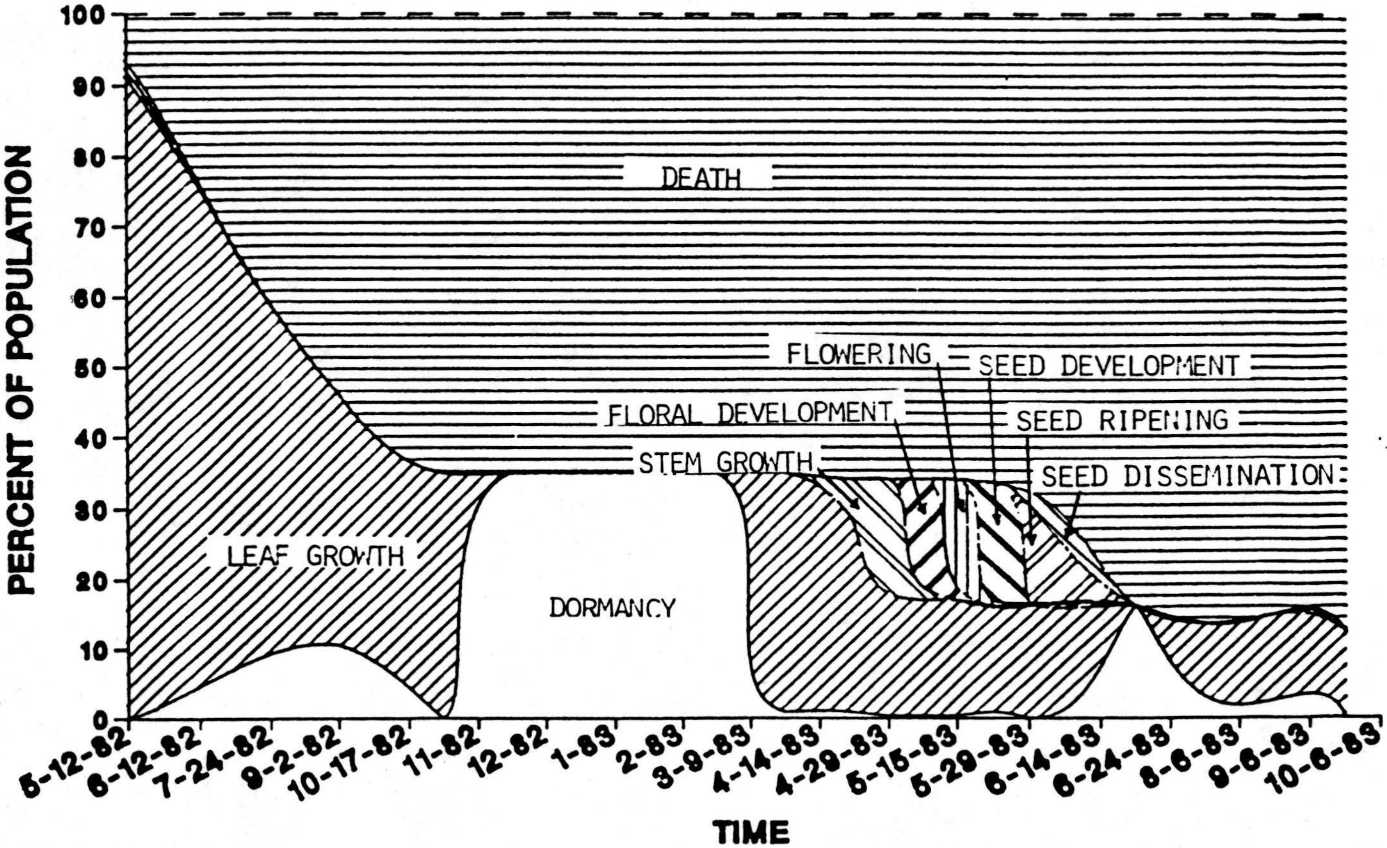

Figure 1. Percentages of Isatis population in various phenological stages over two growing seasons, 1982-83. Plants were selected 30 April 1982.

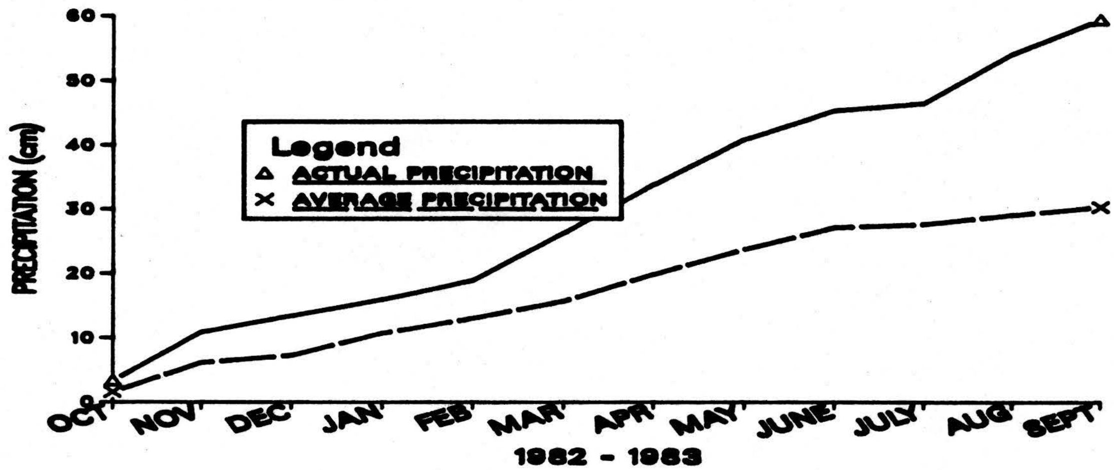

Figure 2. Precipitation (cm) accumulated from October 1982 through September 1983 on the study site.

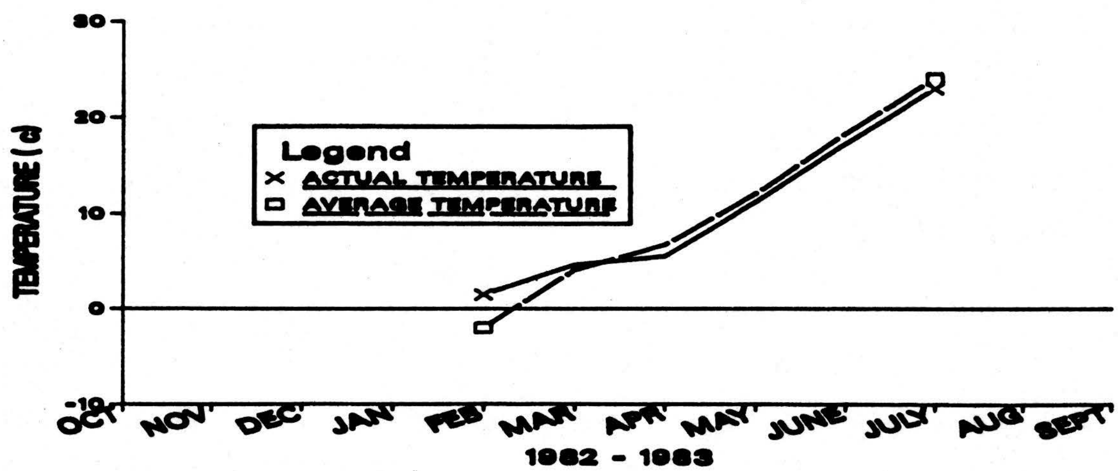

Figure 3. Average and actual monthly temperatures (^{0}C) from February 1983 until July 1983 for the study site.

99 percent in September 1982 to 44 percent in May 1983 (Table 2). The germination rate dropped significantly from 99 percent in September 1982 to 76 percent in October 1982. From October to December, no significant increases or decreases occurred in the germination rate. For this time period, the mean percent germination was 77 percent. In January 1983, the germination rate rose to 89 percent, a significant increase over the previous three months. From January to April, no significant differences were noted in the germination rates. The mean percent germination for this time period was 84 percent. In May, the germination rate dropped significantly to 44 percent. This rate did not differ significantly from the June rate, 48 percent.

The germination rates of seeds stored in the lab did not vary significantly from September 1982 to June 1983. The rates ranged from 100 percent to 88 percent with a 94 percent mean rate (Table 3).

Combined germination and viability rates ranged from 73 to 100 percent (Table 4). The combined rates dropped significantly from 100 percent in September 1982 to 73 percent in November 1982. From November 1982 until March 1983, the combined rate steadily increased from 73 to 100 percent. From March until June, the rates fluctuated between 100 and 94 percent.

The combined viability and germination rates of seeds stored in the lab ranged from 91 to 100 percent (Table 5). No significant differences occurred during the 10 month study. The mean combined rate was 97 percent.

Table 2. Field stored fruits, germinated seeds and mean percent germinated seeds, with standard errors, are shown each month from September 1982 until June 1983.

Month	Stored Fruits	Germinated Seeds	Germinated Seeds	
			Mean (%)	SE
Sep	80	79	98.8	2.4
Oct	160	120	76.3	6.6
Nov	164	120	73.2	6.8
Dec	200	160	80.0	5.5
Jan	191	169	88.5	4.5
Feb	190	156	82.1	5.5
Mar	202	161	79.8	5.5
Apr	203	171	84.0	5.0
May	73	32	43.8	11.4
Jun	214	102	47.7	6.7

Table 3. Lab stored fruits, germinated seeds and mean percent germinated seeds, with standard errors, are shown for each month from September 1982 until June 1983.

Month	Stored Fruits	Germinated Seeds	Germinated Seeds Mean (%)	SE
Sep	68	76	95.0	4.8
Oct	80	71	88.8	6.9
Nov	80	70	87.5	7.2
Dec	80	72	90.0	6.6
Jan	80	76	95.0	4.8
Feb	80	76	95.0	4.8
Mar	80	79	98.8	2.4
Apr	80	80	100.0	0.0
May	80	80	100.0	0.0
Jun	100	97	97.0	2.2

Table 4. Field stored fruits, viable and germinated seeds and mean percent viable and germinated seeds, with standard errors, are shown for each month from September 1982 until June 1983.

Month	Stored Fruits	Viable and Germinated Seeds	Viable and Germinated Seeds	
			Mean (%)	SE
Sep	80	80	100.0	0.0
Oct	160	132	82.5	5.9
Nov	164	120	73.2	6.8
Dec	200	169	84.5	1.3
Jan	191	175	91.6	3.9
Feb	190	178	93.7	3.5
Mar	202	201	99.5	1.0
Apr	203	197	97.0	2.3
May	73	73	100.0	0.0
Jun	214	201	93.9	3.2

Table 5. Lab stored fruits, viable and germinated seed and mean percent viable and germinated seeds, with standard errors, produced each month from September 1982 until June 1983.

Month	Stored Fruits	Viable and Germinated Seeds	Viable and Germinated Seeds Mean (%)	SE
Sep	80	80	100.0	0.0
Oct	80	74	92.5	5.8
Nov	80	73	91.3	6.2
Dec	80	75	93.8	5.3
Jan	80	80	100.0	0.0
Feb	80	77	96.3	4.2
Mar	80	79	98.8	2.4
Apr	80	80	100.0	0.0
May	80	80	100.0	0.0
Jun	100	99	99.0	2.0

Clipping Study

Mortality responses

Initial analysis showed no statistically significant differences for pre- and post-treatment measurements of control plants on the two sites. Thus, data from the two sites were pooled for further analysis.

Mortality percentages for controls and plants clipped at the various heights on 1 May 1982 and monitored over two years followed a consistent pattern (Figure 4). Mortality was greatest for plants clipped 5 cm below ground. Plants clipped 1.5 cm above ground produced the smallest mortality response. The unclipped controls and plants clipped at ground level exhibited intermediate mortality responses. The percent mortality data show the controls and the ground level clippings were not significantly different except for the third post-clipping observation date. There was no significant difference between the mortality percentage of the plants clipped 1.5 cm above ground and plants clipped at ground level. A significant difference did exist for the mortality percentages of plants clipped 1.5 cm above ground and 5 cm below ground.

The mortality percentages for the three clipped heights continued to follow the same pattern even when corrected for the controls (Figure 5). The plants clipped above ground and at ground level showed no significant differences between mortality percentages, but were significantly different from the plants clipped

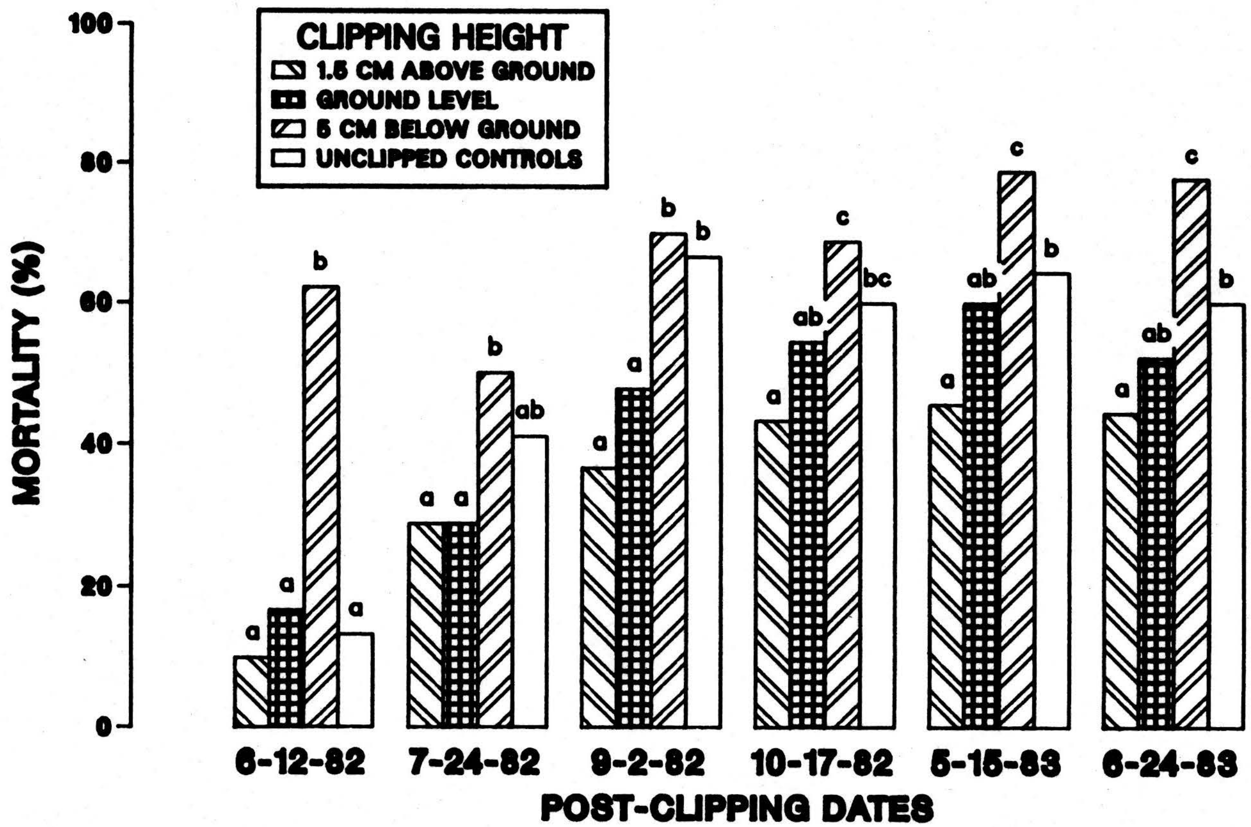

Figure 4. Mortality percentages for controls and plants clipped at three different heights on 1 May 1982. Significant differences ($P<0.05$) between treatments within individual dates are represented by different letters above the mean values.

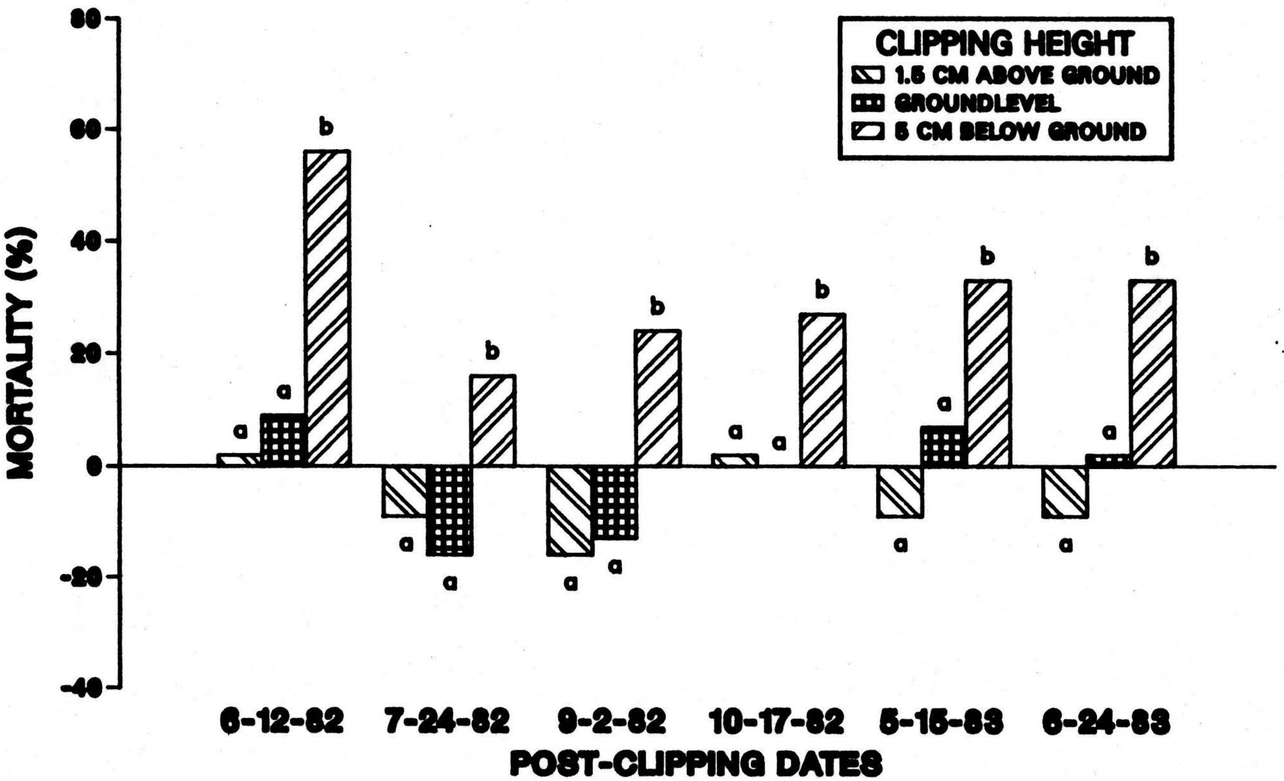

Figure 5. Control-corrected mortality percentages for plants clipped at three different heights on 1 May 1982. Use of superscripts same as in Figure 4.

below ground. Plants clipped above ground had smaller mortality responses than the controls except during the first and fourth post-clipping observation dates.

The mortality percentages for controls and plants clipped at various heights on 25 June 1982 and monitored over two years, also, followed previously described patterns (Figure 6). The plants clipped at ground level or below ground had significantly greater mortality percentages compared to the plants clipped above ground or the unclipped controls. Plants clipped above ground were not significantly different from the unclipped controls.

The control-corrected mortality percentages for the June 1982 clippings continued to follow the previously established pattern (Figure 7). The plants clipped at ground level and below ground showed no significant differences between mortality responses, but did differ significantly from the plants clipped above ground.

Comparison of the May and June 1982 mean mortality percentages indicate the June clippings produced greater mortality for all clipping heights when compared to their May counterparts (Figure 8). The differences between the May and June clippings were significant for all clipping heights at the 95 percent confidence level. The mean mortality percentages continued to show greater mortality for the June clippings compared to the May clippings after mortality percentages were control-corrected (Figure 9). Again, the differences were significant for the three clipping heights.

The mortality percentages for controls and plants clipped at

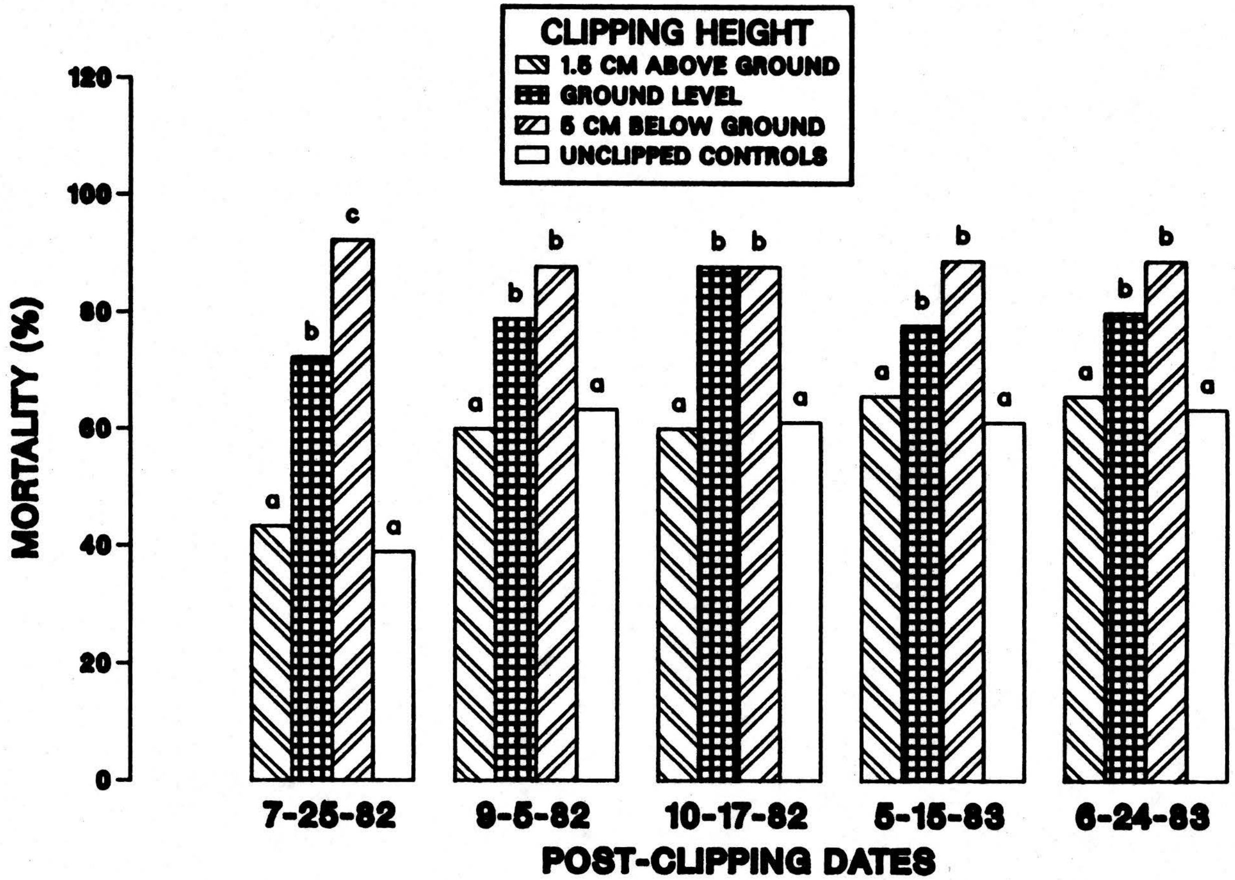

Figure 6. Mortality percentages for controls and plants clipped at three different heights on 25 June 1982. Use of superscripts same as in Figure 4.

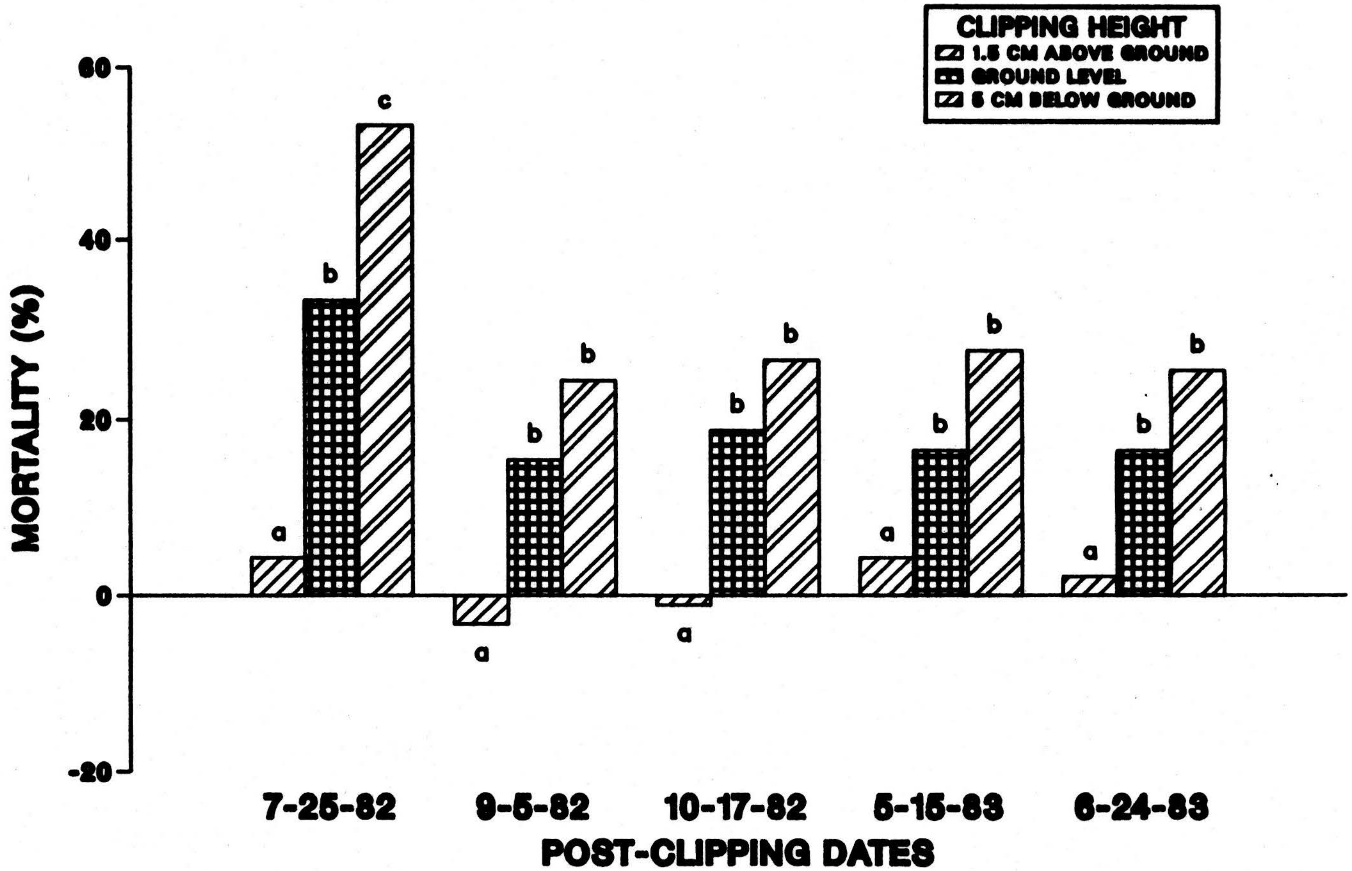

Figure 7. Control-corrected mortality percentages for plants clipped at three different heights on 25 June 1982. Use of superscripts same as in Figure 4.

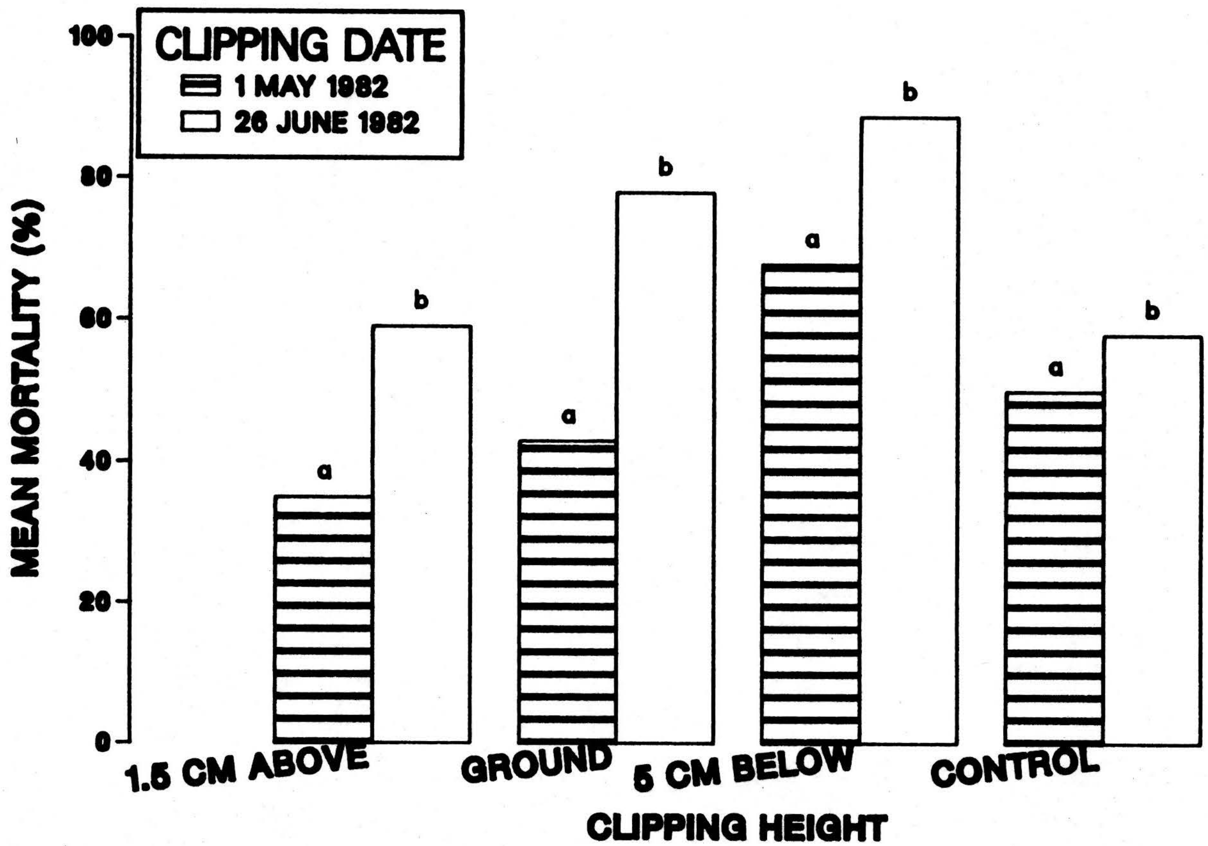

Figure 8. Mean mortality percentages for controls and plants clipped at three different heights on either 1 May 1982 or 25 June 1982. Use of superscripts same as in Figure 4.

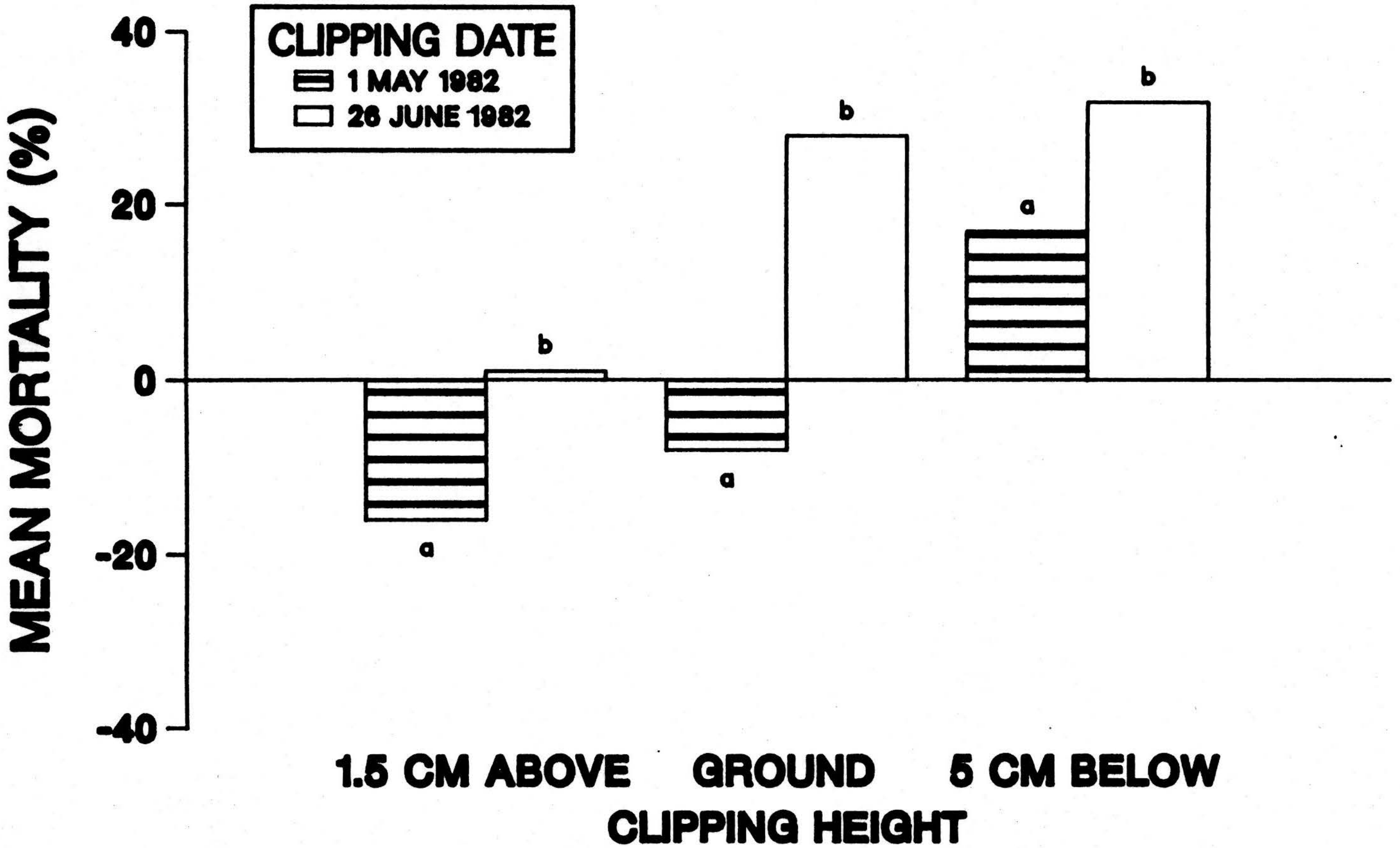

Figure 9. Control-corrected mean mortality percentages for plants clipped at three different heights on either 1 May 1982 or 25 June 1982. Use of superscripts same as in Figure 4.

various heights on 1 April 1983 showed two distinct patterns (Figure 10). The patterns are separated by a missing post-clipping observation date. On 6 August 1983 no green plant material could be found on either site, possibly due to a summer dormancy caused by high temperatures and a lack of moisture. Prior to this dormancy period, the plants clipped below ground had the greatest mortality followed by plants clipped at ground level. Plants clipped above ground and the unclipped controls had the lowest mortality percentages and were not significantly different at the 95 percent confidence level. After the dormancy period, the plants clipped above ground and below ground had the greatest mortality percentages but they were not significantly different. The plants clipped at ground level and the unclipped controls had the lowest mortality percentages and were, also, not significantly different.

The control-corrected mortality percentages for the three clipping heights followed the pattern previously described (Figure 11). The three heights were significantly different for the first post-clipping observation date. For the second post-clipping observation date, the above ground and ground level clippings did not have significantly different mortality responses, but both were significantly less than the below ground clipping. The above ground and below ground clipping heights did not produce significantly different mortality responses at the 95 percent confidence level during the final two post-clipping observation dates, but the ground level clipping height did show significantly lower mortality

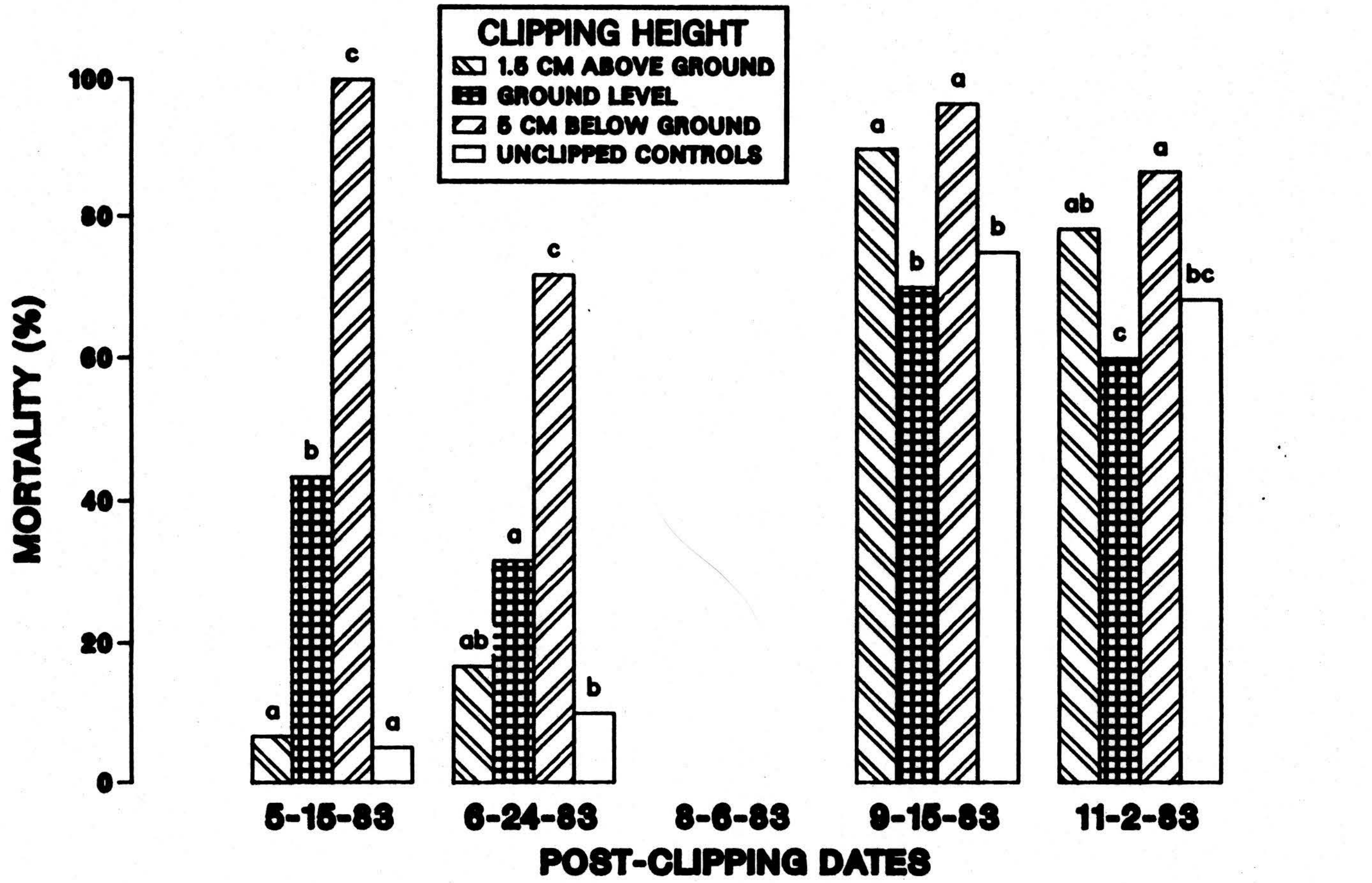

Figure 10. Mortality percentages for controls and plants clipped at three different heights on 1 April 1983. Use of superscripts same as in Figure 4.

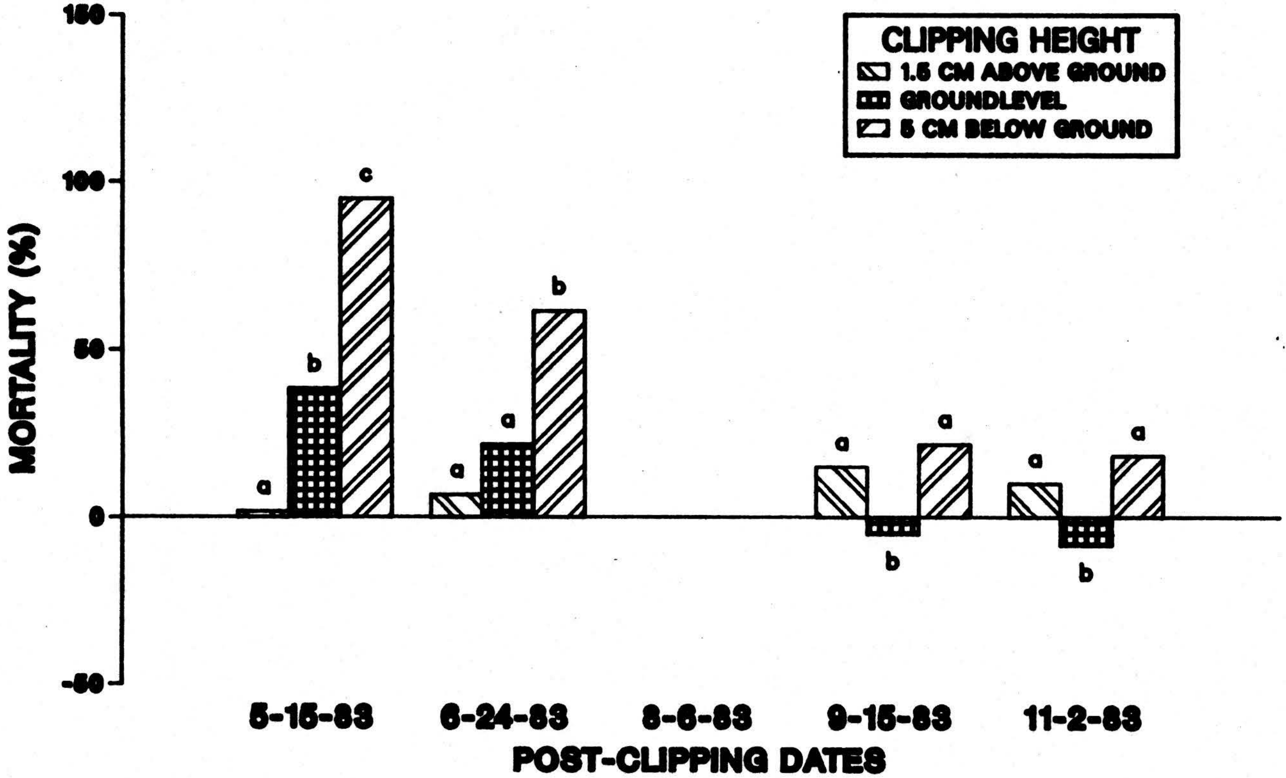

Figure 11. Control-corrected mortality percentages for plants clipped on 1 April 1983. Use of superscripts same as in Figure 4.

percentages at the 95 percent confidence level compared to the other two clipping heights.

Survival predictions

No significant relationships existed between rosette diameter, basal diameter, basal leaf number and the ability of a plant to survive clipping. The basal diameters, rosette diameters and basal leaf numbers of the living plants directly overlapped the dead plants.

Flowering responses

The ability of plants to flower after clipping was studied for two years. The plants clipped during bolting and after flowering (1 May and 25 June 1982) did not re-bolt and flower during the 1982 season. A year later, a significantly greater percentage of plants clipped above ground and at ground level during bolting flowered when compared to the flowering percentages of plants clipped at the same time below ground and the unclipped controls (Figure 12). Of the plants clipped on 25 June 1982, a significantly greater number flowered a year later after being clipped above ground than after being clipped below ground (Figure 12).

Plants clipped on 1 April 1983 bolted and flowered during the 1983 season. Plants clipped above ground and the unclipped controls produced significantly greater flowering percentages than the plants clipped at ground level or below ground (Figure 12).

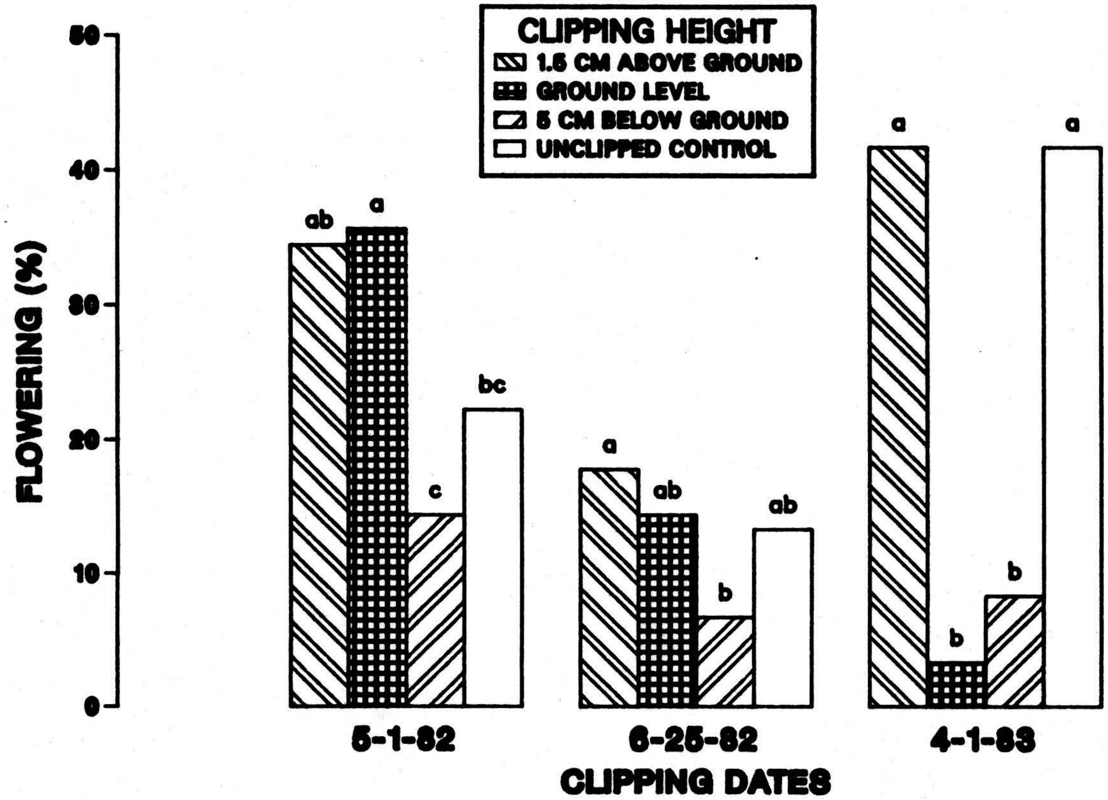

Figure 12. 1983 flowering percentages for controls and plants clipped at three different heights on three different clipping dates. Use of superscripts same as in Figure 4.

Flowering predictions

The ability of a plant to flower could not be predicted from plant size. Basal diameter, rosette diameter and basal leaf number of bolted plants directly overlapped unbolted plants.

Seed number

The number of seeds produced per plant by all the treatment times and treatment heights ranged from 194 to 632 (Table 6). For the May and June 1982 treatments, the plants clipped below ground produced 49 percent and 37 percent fewer seeds than the controls. No seeds were produced by the plants clipped below ground in 1983. For the May 1982, June 1982 and April 1983 treatments, the plants clipped above ground produced 3 percent more seeds, 23 percent fewer seeds and 16 percent fewer seeds than the controls, respectively. The difference between the highest producing treatment time, May 1982, and the lowest producing treatment time, June 1982, for the plants clipped above ground was only 62 seeds. The difference between the highest producing treatment time, April 1983, and the lowest producing treatment time, May 1982, was only 68 seeds for the controls. The difference between the highest and lowest producing treatment times was 253 for the plants clipped at ground level. The plants clipped below ground produced a difference of 75 seeds between the highest and lowest producing treatment times.

Stalk height

The flowering stalk heights ranged from 41 cm to 74 cm for all

Table 6. Plants and mean fruit numbers, with standard errors, produced by combined treatment times and treatment heights. The treatment times designated by 1, 2 and 3 are 1 May 1982, 25 June 1982 and 1 April 1983, respectively. The treatment heights designated by 1, 2, 3 and 4 are 1.5 cm above ground, ground level, 5 cm below ground and unclipped controls, respectively.

Treatment Time	Treatment Height	Plants	Mean Fruits	SE
1	1	29	389	67.1
1	2	29	525	90.8
1	3	12	194	42.8
1	4	17	378	74.7
2	1	15	326	62.9
2	2	12	379	110.9
2	3	6	269	140.0
2	4	13	424	91.0
3	1	24	354	81.1
3	2	1	632	0.0
3	3	0	0	0.0
3	4	19	446	95.2

treatment heights and treatment times (Table 7). The plants clipped at ground level consistently had the tallest stems. The plants clipped above ground, at ground level and the unclipped controls alternated between the intermediate and shortest stem heights.

Table 7. Plants and mean flowering stalk height (cm), with standard errors, from combined treatment heights and treatment times. The treatment times designated by 1, 2 and 3 are 1 May 1982, 25 June 1982 and 1 April 1983, respectively. The treatment heights designated by 1, 2, 3 and 4 are 1.5 cm above ground, ground level, 5 cm below ground and unclipped controls, respectively.

Treatment Time	Treatment Height	Plants	Mean Stalk Height	SE
1	1	30	70	2.4
1	2	30	73	2.5
1	3	13	62	3.4
1	4	20	66	2.2
2	1	16	72	2.2
2	2	13	68	3.5
2	3	6	66	7.0
2	4	13	63	2.9
3	1	24	66	2.3
3	2	2	74	1.3
3	3	6	46	6.1
3	4	25	68	3.4

CHAPTER V

DISCUSSION

Control of dyers woad in Utah became a major concern of farmers and ranchers during the 1980s. Herbicidal and mechanical methods of control became available for controlling dyers woad on cropland (Evans and Chase 1981). However, due to the negative effects of herbicides and machinery on associated desirable forage, generally rough topography and questionable present net worth, these methods of control were not suitable for rangelands. A possible alternative approach could be biological control through grazing. Before launching a full scale grazing study, autecological studies and preliminary grazing simulation were deemed to be prudent.

Phenology Study

Management considerations for proper dyers woad control were contingent upon finding the most susceptible phenological stage(s). A problem developed when no phenological information was available for this or future studies. Dyers woad phenological stages were followed from May 1982 to November 1983 on either a biweekly or monthly basis depending upon the growth rate.

Dyers woad began growth early in the spring. Leaf growth was initiated as early as March or as soon as the snow melted. Germination of new seedlings occurred slightly later during April and May. The new seedlings grew until mid-summer when high temperatures and low precipitation forced them into a dormancy. About 50 percent of the original 90 rosettes survived the summer dormancy and regrew in the fall. Fall growth continued until snow covered the ground in November. At this point, dyers woad lay dormant until the following spring. The following spring, leaf growth was again initiated by 35 percent of the original rosettes with half of these beginning to form stems as early as mid-April. At this point dyers woad literally "bolted." The average stem grew 10 cm per week for six weeks. The total process from bolting through flowering and seed formation took approximately eight weeks. After seed formation, all flowering plants had completed their life cycles and died. Although this scenario describes dyers woad as a biennial, the actual ages of the plants were unknown. Longer term studies of a larger population of plants from seed will be required for more conclusive results.

Dyers woad appears to be most vulnerable to clipping during leaf growth. Once stem growth is initiated, the plant will strive to complete its life cycle. Successful control should occur during the leaf growth stage for plant control. Control after bolting occurs may prevent the plant from flowering, but the most probable outcome will be only a delayed flowering.

Germination Study

The life of dyers woad seeds was studied to determine the time period needed for population reductions. If dyers woad seeds had a one year life, then possibly a control program would be complete one year after the first plant flowered.

The germination and viability of dyers woad seeds were studied on a month-to-month basis from September 1982 to June 1983. Basically, germination decreased over time with several significant differences. The first significant decrease occurred from September 1982 to October 1982 which coincided with a change from conditions favorable for germination to conditions unfavorable for germination. The conditions favorable for germination were adequate moisture and temperatures between 3°C and 25°C (Young and Evans 1971). Another significant difference occurred from December 1982 to January 1983 in the lab. This difference was an increase and the logical explanation available for the difference was an equipment problem. The final significant decrease occurred from April 1983 to May 1983 which again coincided with a switch from favorable to unfavorable germination conditions in the field. Thus, germination decreased from almost 100 percent to less than 50 percent during the first ten months of seed life.

Although seed germination decreased over time, seed viability did not decrease drastically over time. The seeds remained extremely viable throughout the study. The average viability percentage was 91 with a range of 73 to 100. Obviously, the life of dyers woad seeds will dictate a control period of more than one year.

The seeds stored in the laboratory had mean germination and viability percentages of 94 and 97. Obviously, the ability of laboratory stored dyers woad seeds to germinate and survive does not decrease during the first year.

This ten month study indicates the ability of dyers woad seeds to germinate decreases over time, but their ability to survive does not drastically decrease with age. Dyers woad produces a hardy seed which can survive at least one year, germinate under a wide range of temperatures, and does not require a dormancy period (Young and Evans 1971, Evans and Gunnell 1982). These factors suggest a long term control program will be needed to deplete a viable dyers woad seed source.

Clipping Study

The heart of this study was to determine the feasibility of dyers woad control by livestock grazing. Initially, the expense of a grazing study prohibited a full scale project. Rather, simulated grazing was used to attempt to justify the time and expense of a livestock grazing study.

The grazing simulation chosen was clipping. Clipping was used to cut off dyers woad plants one time below ground, at ground level or above ground on 1 May 1982, 25 June 1982 and 1 April 1983. The clipping heights provided comparisons between simulated plowing, hand rogueing and grazing control. The clipping times allowed comparison of utilization effects from early spring to mid-summer or during the growing season.

Mortality responses

Clipping below ground (plowing simulation) consistently resulted in the greatest mortality for plants treated on all three dates. Clipping above ground and at ground levels on 1 May 1982 produced smaller mortality percentages than the natural mortality observed on the unclipped controls except during the first period. Thus, grazing or hand rogueing in late spring killed fewer dyers woad plants than simply leaving them untreated. In other words, a one time clipping in the late spring stimulated survival.

Clipping above ground and at ground level on 25 June 1982 produced greater mortality percentages than the unclipped controls, except during two periods. Also, the June clipping produced greater mortality than the earlier clippings. Thus, grazing or hand rogueing in mid-summer killed more plants than not treating them and killed more plants than earlier clipping. This later clipping produced the desired effect: death.

Death of the treated weeds was a product of several factors. Clipping cannot take total credit for the greater mortality rates produced in mid-summer. In addition to clipping, high temperatures and little precipitation restricted regrowth and added stress to the weakened plants.

Clipping above ground or simulated grazing on 1 April 1983 produced small mortality rates. These rates were not significantly different from the unclipped controls. The ground level and below ground clippings produced greater mortality rates than the controls.

These trends continued until mid-summer. Thus, initially hand rogueing or plowing in the early spring will produce mortality. Grazing simulation did not produce a mortality effect drastically different from the unclipped controls. After the mid-summer dormancy period, the mortality rates increased for all treatment heights. The controls and above ground clippings produced the most significant increases. These increased mortality rates were due to clipping plus completed life cycles.

The data from this clipping study indicated a one time above ground clipping or simulated grazing will not increase mortality, but rather will stimulate survival and flowering. The more drastic one time clippings at ground level and below ground or simulated hand rogueing and plowing produced greater mortality rates, but these methods were not practical for rangelands. Possibly a more drastic above ground clipping, such as multiple clippings, would result in increased mortality.

Survival responses

No definite relationships were found between plant size and the ability of the plants to survive clipping. Possibly, a larger sample size would show a relationship. Werner (1975) and Gross (1981) followed 3900 and 2600 individuals of other biennial forbs, respectively. This study followed 960 individuals.

Flowering responses

Initially, clipping was thought to delay flowering and subsequent death. This was the rule for plants clipped in 1982. Only one plant clipped during 1982 flowered in 1982. The majority flowered one year later. In 1983, above ground early spring clipping (1 May 1982) resulted in significantly greater mean flowering than the controls or those clipped below ground. The 25 June 1982 treatment showed no significant differences between the below ground, ground level clippings and the unclipped controls, but the above ground clipping did produce significantly more flowering than the unclipped controls. Thus, above ground mid-spring and summer one time clipping apparently stimulated flowering one year later.

The 1 April 1983 clippings did flower during the 1983 growing season. Flowering was apparent for plants clipped at ground level or below ground, but was delayed. Delayed flowering was not apparent on plants clipped above ground. There was no significant difference between average flowering percentages of the unclipped controls and those clipped above ground. Apparently, early spring grazing would not delay or reduce flowering.

<u>Flowering predictions</u>

Dyers woad plant size could not be directly correlated to the ability of a plant to flower. This study was limited by a sample size of 202 individuals divided between three treatment times and four treatment heights. A larger sample size might expose a correlation between plant size and flowering.

Seed number

Seed production was influenced by the treatment height. Plants clipped below ground consistently produced the smallest number of seeds. Plants clipped at ground level and above ground consistently produced high and moderate seed numbers, respectively. The unclipped controls fluctuated around the ground level and above ground treatments. Thus, seed production was most reduced by plowing simulation. Hand rogueing appeared to stimulate seed production.

Stalk height

Stalk heights were influenced by treatment times and treatment heights. Clipping at ground level consistently produced the tallest stems. No general remarks can be made about the other clipping heights. Thus, clipping does not appear to reduce the vigor of flowering plants.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Control of dyers woad on Utah rangelands will continue to be a major concern of farmers and ranchers. Biological control (grazing) once during a growing season will not reduce dyers woad populations. Hopefully, the results of the simulated control methods and supporting autecological studies will provide some initial answers and lead to further questions and research on dyers woad control.

Phenology Study

Dyers woad is a persistent plant that alternates between rapid growth and dormancy. Spring time produces germination, stimulated rosette growth and flowering followed by seed formation and dissemination. Summer's dry hot climate forces dyers woad into dormancy. The cool wetter weather of fall stimulates germination and resumed leaf growth. Winter again produces dormancy.

Dyers woad may alternate between rapid rosette growth and dormancy for several years before flowering and death occurs. The two year phenological study was dominated by seedling death and rosette leaf growth the first year. During the second year, approximately half of the remaining plants flowered and died and the other half continued growing as rosettes. These remaining rosettes may have flowered during the third year. Future studies which follow larger populations started from seed through death are needed to determine the average dyers woad life span.

Germination Study

The ability of dyers woad seeds excised from their fruits to germinate over time varied according to their storage conditions. Seed stored in the field and exposed to the elements of nature had decreasing germination rates. Seed stored in the laboratory at relatively constant temperatures and no moisture had high, stable germination rates. The combined germination and viability rates did not drastically decrease over time for either group. Thus to ensure depletion of viable seed sources, farmers and ranchers will need to embark on long term control programs. The ability of seeds not excised from their fruits to germinate over a longer period of time is a point to investigate with future research. The actual length of time required for these control programs is difficult to estimate with data collected from unnatural field conditions. Future research should attempt to simulate field conditions such as temperature, moisture and light conditions with seed bearing fruits.

Clipping Study

Control of dyers woad on rangeland is going to require a more drastic approach than grazing once during a growing season. Simulated grazing treatments (one time clipping above ground) stimulated plant growth and survival. Treatments in the late spring and early summer delayed flowering for one year, but early spring treatments did not delay or depress flowering at all. The time of these treatments did not affect the final production of seeds.

Simulated plowing treatments (one time clipping below ground) depressed plant growth, survival, seed production, and flowering stalk heights. This situation held true for all treatment times.

These results appear to contradict the results of past observations by Parker (1980), but his methods deviated from those used in this study. His study area was grazed by sheep throughout the growing season rather than using a one time grazing treatment (Jensen 1985). His study area had been intentionally grazed prior to the study whereas the study site in this project had not been grazed for 20 years.

Simulated hand rogueing treatments (one time ground level clipping) produced variable survival rates compared to the other clipping treatments and controls. The flowering response of plants receiving these treatments mimicked the controls by displaying neither depression nor stimulation, but seed production and flowering stalk growth were stimulated.

Relationships between plant size and the ability to survive or flower were not discovered. The lack of discovery has been attributed to an inadequate sample size. Future studies involving larger sample sizes may reveal the existence of such relationships and aid in selection of a proper control method and time.

In conclusion, the simulated one time grazing did not reduce dyers woad populations, but rather stimulated growth. Plowing and hand rogueing reduced dyers woad populations, but are not practical control methods on rangelands. However, the simulated plowing and hand rogueing did indicate a more drastic method than a one time grazing will reduce dyers woad populations. Repeated grazing in the form of multiple clippings should be explored in future studies.

LITERATURE CITED

Anderson, B. A. and A. H. Holmgren. 1966. Mountain plants of northeastern Utah. Circular 319, Utah State Univ. Ext. Serv., Logan. 148 p.

Association of Official Seed Analysts (AOSA). 1970. Rules for testing seeds. Proceedings of the Association of Official Seed Analysts 60(2). 116 p.

Baker, H. G. 1965. Plants and civilization. Wadsworth Publ. Co., Inc., Belmont, California. 183 p.

Bonner, R. T. 1974. Seed testing. p. 136-152 In: Seeds of woody plants in the United States. U.S. Dept. Agriculture, Agricultural Handbook 450.

Cochran, W. C. and G. M. Cox. 1957. Experimental designs, 2nd ed. Wiley, New York. 103 p.

Evans, J. O. 1976. Dyers woad-serious weed threat. Utah Farmer-Stockman 96:21.

Evans, J. O. and R. L. Chase. 1981. Dyers woad control. EL 199. Utah State Extension Service, Logan. 6 p.

Evans, J O. and R. W. Gunnell. 1982. An evaluation of control strategies for dyers woad in crop and rangelands. Proc. Western Soc. Weed Sci. 35:32-33.

Everett, R. L., P. T. Tueller, J. B. Davis, and A. D. Brunner. 1980. Plant phenology in galleta-sagebrush associations. J. Range Manage. 33(6):446-450.

Gilkey, H. M. 1957. Weeds of the Pacific Northwest. Oregon State College. 441 p.

Gross, K. L. 1981. Prediction of the fate from rosette size in four "biennial" plant species: Verbascum thapsus, Oenothera biennis, Daucus carota, and Tragopogon dubius. Oecologia 48:209-213.

Higgins, R.E. and D. Tovey. 1972. Dyers woad ... search and destroy. Current Information Series No. 176. Univ. of Idaho College of Agric. Coop. Ext. Serv., Moscow. 2 p.

Holmgren, A. H. and B. A. Anderson. 1976. Weeds of Utah. Special Report 21. Utah Agr. Exp. Sta., Utah State Univ., Logan. 115 p.

Holm, L., J. V. Pancho, J. P. Herberger, and D. L. Plucknett. 1979. A geographical atlas of world weeds. Wiley, New York. 391 p.

Hurry, J. B. 1930. The woad plant and its dye. Oxford Univ. Press, London. 328 p.

Jensen, M. 1985. Personal communication.

King, L. G. 1966. Weeds of the world: Biology and control. Interscience Publishers, Inc., New York. 526 p.

Kotter, C. M. 1976. Battle lines forming against dyers woad. Utah Farmer-Stockman 96:18-19.

Lacey, J. and P. Fay. 1984. Another serious weed threat. Montana Farmer-Stockman 71(19):46-47.

Marble, B. 1984. Personal communication.

Moore, R. P. 1973. Tetrazolium staining for assessing seed quality. p. 347-366 In: Seed ecology. W. Heydecker, ed. Pennsylvania State Univ. Press, University Park.

Norr, J. D. 1983. Personal communication.

Parker, K. J. 1980. Intermountain range threat-dyer's woad. Utah Farmer-Stockman 100:4A-5A.

Parker, K. J. 1982. Personal communication.

Ryan, T. A., Jr., B. L. Joiner, and B. F. Ryan. 1976. Minitab Student Handbook. PWS Publishers, Boston. 341 p.

Rydberg, P. A. 1917. Flora of the Rocky Mountains and adjacent plains. Published by author. 1110 p.

Steel, R. G. D. and J. H. Torrie. 1980. Principles and procedures of statistics. McGraw-Hill Book Co., Inc., New York. 633 p.

Soil Survey Staff. 1975. Soil Survey of Box Elder County, Utah: Eastern Part. Soil Conservation Service, USDA. 231 p.

Varga, W. A. and J. O. Evans. 1978. Dyer's woad: from cultivated to cursed. Utah Science 39:87-89.

Welsh, S. L. and G. Moore. 1973. Utah plants-Tracheophyta, 3rd ed. Brigham Young Univ. Press, Provo. 474 p.

Welsh, S. L. and J. L. Reveal. 1977. Utah flora: Brassicaceae (Cruciferae). Great Basin Naturalist 37:279-365.

Werner, P. A. 1975. Predictions of fate from rosette size in teasel (*Dipsacus fullonum* L.). Oecologia 20:197-201.

West, N. E. and R. W. Wein. 1971. A plant phenological index technique. BioScience 21:116-117.

Young, J. A. and R. A. Evans. 1971. Germination of dyers woad. Weed Science 19(1):76-78.